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A framework of indicators to measure project circularity in construction circular economy.

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Abstract

The construction circular economy (CCE) literature lacks a holistic framework for systematic assessment of project “circularity”; thereby impeding industry restructuring and full transition to CE. The proposed 'Project Lifecycle Assessment Circularity Indicators and Themes (PLACIT)’ framework supports thematic "circularity" ratings in construction projects using twelve “circularity” indicators (CIs), representing high level requirements of CE, grouped in five themes relevant to project lifecycle stages. This helps identify areas of good practice, and those requiring circularity improvements. A systematic literature review, structured in line with PLACIT, revealed an increasing association between CE and ‘constructability’, but varying engagement with CIs. The predominant engagement with indicators within the industry’s comfort zone indicates supply-push practices focusing on aspirational CE design solutions, and CE management; missing opportunities from engaging with more demand-pull indicators e.g. reduced material inputs, and embedding circular materials in design practices. Full transition to CE will require engaging with a wide range of indicators throughout the whole project lifecycle in a more complex network. Moreover, PLACIT has potentials to set clear boundaries between ‘sustainability’ and CE concepts, currently ill-defined in the literature. Future research (APM-supported) will seek to validate PLACIT using expert feedback, and use circularity ratings to support decision-making in construction.

1. Introduction

1.1 Consideration of a circular economy (CE) in construction

CE, as an emerging paradigm in project management, has its roots in ideologies and schools of thought such as regenerative design, performance economy, cradle-to-cradle, and industrial ecology (Sauvé et al., 2016; Rizos et al., 2017; De los Rios & Charnley, 2017; EMF, 2013). These roots can be traced back to the 1960s, with papers such as Boulding (1966) referring to cyclical ecological systems that place the concept in the context of present-day industrial ecology (Leising, et al, 2018). The increasing interest in issues such as sustainability and circularity has produced a wide-ranging body of literature as the boundaries of concepts such as CE seek to be established, distinct from core sustainability research. The literature ranges from the consideration of component-level circularity in building materials stocks (eg. Arora et al, 2019), through the management of replacement material flows (e.g Stephan, Athanassiadis, 2018) and the perspective of buildings as material banks (eg. Copeland, Birec, 2020), to the redesigning of procurement routes and business models through consideration of factors such as regulatory barriers (EC, 2016). In short, "… the actual definition, objectives, and forms of implementation of the CE are still unclear, inconsistent, and contested. Different actors and sectors are thus articulating circular discourses which align with their interests …" (Friant et al, 2020). Such a raucous diversity of discourse risks creating unproductive dichotomies, with the relationship between sustainability and CE being a key example.

The body of discourse around the adoption of a holistic, sustainability-based approach to CE requires reshaping the entire chain of production, consumption, distribution, and recovery

(Ghisellini et al., 2018). In scope, this restructuring is ultimately required at the scale of supply networks but, at present, the literature focus is mostly on the less challenging supply chains, such as the CE concept frequently being viewed from the closed material loops and waste management perspectives (e.g. Sauvé et al., 2016; De los Rios & Charnley, 2017; Preston, 2012). The relationship between CE and sustainability can therefore argued to be not addressed in a sufficiently explicit manner, resulting in "… blurring their conceptual contours and constrains the efficacy of using the approaches in research and practice …" (Geissdoerfer et al., 2017). The framework presented here seeks to establish clear conceptual contours relevant to the explicit assessment of circularity, as a valid outcome in itself, while respecting the relationship to the holistic consideration of sustainability, and thereby achieving greater efficacy in the assessment of project circularity.

The CE concept is frequently presented in research literature as subordinate to sustainability; essentially, as a pathway to product sustainability (De los Rios & Charnley, 2017) or a strategy to achieve a more 'sustainable development' and a harmonious society (Ghisellini et al., 2016). Indeed, the current 'contours' of sustainability discourse are arguably around issues such as societal change, at levels ranging from the individual to national, of sustainability behaviours through communication (e.g. Berkeley, 2020), the inclusion of societal needs within procurement (e.g. Salvioni, Almici, 2020) and the rethinking of business models beyond traditional competitive/profit-making factors (e.g. Circulab, nd). However, in the context of construction industries (the focus of this research being the UK construction industry), CE research focuses on issues such as waste management in a manner having little linkage with sustainable development (Kirchherr et al., 2017), while construction sustainability research typically addresses high-performance green buildings and aspects of retrofitting (Sanchez and Haas, 2018), and energy consumption and carbon emissions (Pomponi and Moncaster, 2016).

In 2015, the Ellen Macarthur Foundation (EMF, 2015a) noted the lack of a valid framework and tools to measure the overall transition of different industries from ‘linear’ to ‘circular’ models, a factor which could be directly linked to the ambiguous scope of CE. Furthermore, Sauvé et al. (2016) argue that CE tends to have narrower objectives than those of sustainable development; it includes a fragmented collection of concepts derived from different scientific fields, some being poorly established (Korhonen et al., 2018). The diversity of concepts, schools of thought, and stakeholders operating in significantly different environments, have all blurred the CE concept (Kirchherr et al., 2017). CE research is characterized by a partial approach (Pomponi and Moncaster, 2017), engaging with conceptual discussions about individual concepts of CE, arguably with no practical implementation strategies provided (Suárez-Eiroa et al., 2019). In the construction industries, trends of CE research include construction and demolition (C&D) waste management (Ghisellini et al., 2018), sustainable construction (Kibert, 2016), and industrial symbiosis (Smol et al., 2015).

Whilst there have been undoubted improvements in the performance of construction industries regarding aspects of sustainability such as energy consumption and waste reduction, in the UK context such improvements appear to have made little contribution to the full transition of the industry to CE. For example, the UK 'Statistics on Waste' report (DEFRA,

2019) identifies recovery rates from non-hazardous construction and demolition (C&D) waste of 90%, significantly exceeding the 70% target set for 2020 by the EC Waste Framework Directive. Nonetheless, this apparent sustainability success does not give the whole picture, in that the same report shows the UK construction industry as responsible for more than 60% (130MT/year) of all waste produced in the UK. This unenviable position potentially evidences that the 'easy hits' concerning waste reduction, as one factor in sustainability, have been addressed leaving the more challenging (for a stand-alone perspective on waste management) aspects requiring solutions. Arguably, part of the problem flows from the definition of 'waste', particularly (as far as circularity is concerned) with respect to differentiating between waste and resource when both arise (in the construction context) anthropogenically.

The definition of 'waste' has evolved but a useful definition is provided in Directive 2008/98/EC as "any substance or object which the holder discards or intends or is required to discard" with, in circularity terms, the key word being 'discard'. By creating a perspective in which what would previously have been regarded as only being fit to 'discard' becomes regarded as a resource to be used, the industry will no longer have to make use of permissible exceptions such as the possibility to class something as either a by-product or as having met specified end-of-waste criteria (which do not automatically result in reuse), rather than as 'waste' (DEFRA, 2012). The consideration of waste is further examined in Sections 3 and 5.

An additional consideration is the industry's perceived general reluctance to innovate in a significant manner, as evidenced by the low level of adoption for offsite technologies (Young et al, 2020). An approach focused on the specifics of transitioning the industry to a circular economy could provide an improvement route less overwhelming than a holistic drive for sustainability. However, such an approach would need to cut through the previously considered discourse in a manner that allows for clear and explicit assessment of the transition process.

1.2 Measuring the rransition to CE: a brief history of "circularity" assessment

Reviewing CE literature in general reveals various attempts to identify principles, strategic focus areas, and related metrics or indicators to measure the transition to CE. Some of the earliest work (of relevance in this context) was reported in 2013. Su et al. (2013) categorized CE practices into four areas: production, consumption, waste management, and other support; each included practices at micro, meso and macro managerial levels. The first three areas perceived CE from the material perspectives, whereas the fourth highlighted the role of governments and NGOs in promoting CE. The Ellen MacArthur Foundation (2013) introduced a generic framework of four "building blocks" to promote the transition to CE, including: circular product design and production; new business models; and building reverse cycle and cross-cycle collaboration. The European Environmental Agency (2016) provided a generic set of policy questions for CE assessment, classified under five main areas: material input, eco-design, production, consumption, and waste recycling. This framework was adopted by Elia et al. (2017) to assess CE concepts based on their ability to satisfy five CE principles: reducing material inputs, reducing material losses, reducing emissions, using renewable/recyclable resources, and increasing product durability. Suárez-Eiroa et al. (2019) used the same principles, plus two transversal principles ('designing for CE' and 'educating for CE'), to group practical strategies of CE. Nonetheless, Friant (2020) identified five remaining challenges to CE. These are:

1. Systemic thinking on entropy, growth, capitalism, and decoupling
2. The materials, energy, and biodiversity nexus
3. Evaluating and assessing the full impacts of a circular economy
4. Governance, social justice, and cultural change
5. Alternative visions of circularity

Of these, the challenge of most relevance in the context of this paper is the third challenge: evaluating and assessing the full impacts of a circular economy. Work such as the ‘Circularity Indicators Project’ (EMF, 2015a) suggested a tool to measure how advanced products and companies are with respect to transitioning to CE. This tool uses four criteria: inputs in the production process, utility during in-use stage, destination after use, and efficiency of recycling. Such tools are of possible value in the development of new products and components (arguably at the micro level), while toolkits such as the ‘Delivering the CE’ report (EMF, 2015b) focus on measuring "circularity" at the national (macro) level by using four metrics. Each metric is linked to one or more relevant assessment criteria; resources productivity, circular activities, waste generation, and energy consumption and greenhouse gas emissions.

Hitherto, the confusion between ‘sustainability’ and ‘circularity’ metrics remains apparent; and CE-focused literature remains populated with fragmented discussions about different CE requirements. While these individually contribute to CE knowledge, a ‘helicopter’ perspective is required if the fragments are to be connected so as to achieve a more valuable contribution.

For example, Sanchez and Haas (2018) argue that CE principles must be integrated into the construction process, which can be facilitated by more involvement of clients as key drivers in project teams (Haugbølle and Boyd, 2017), including CE decision gates and “pre-project” or “front-end” planning (Sanchez and Haas, 2018), and the inclusion of design and education as transversal elements (Suárez-Eiroa et al., 2019). Two industry reports provided attempts to establish links between CE requirements and thereby promote CE to the construction industry:

1. Ellen MacArthur Foundation and CE100 Network’s ReSOLVE framework (EMF, 2016),
2. UK Green Building Council report: Circular economy guidance for construction clients (UKGBC, 2019).

The ReSOLVE framework focused on adoption of principles (Regenerate, Share, Optimize, Loop, Virtualize, Exchange), each having a claimed individual contribution to enhance CE in building projects. UKGBC’s report proposed a more holistic approach to “enable construction clients to include more ambitious circular design and construction principles in project briefs for non-domestic built assets” (UKGBC, 2019) by providing clients with lists of high-level CE principles (for inclusion in project briefs) relevant to project delivery; however, it does not extend beyond the project brief (RIBA Stages 0 to 2. RIBA (2020)) and largely presents CE principles, with use of a hierarchy to guide development of CE aspirations into metrics for inclusion in the project brief. Moreover, neither report provides a valid and holistic framework of indicators whereby “circularity” throughout the building project lifecycle can be assessed. This, in turn, does not allow for the granular comparison of circularity within different options being considered for a project brief; the client or project team has to be content with, for example, identifying short and long-life components (differing CE stances being adopted in response to component lifespan).

In terms of the provision of analysis granularity, approaches such as that taken by Gervasio and Dimova (2018), in their proposed LCA model for buildings, is more effective than the reports mentioned previously, as evidenced by its focus on development of the modular approach adopted in CEN TC350 (CEN nd) when providing standards for a consistent methodology by which to assess circularity (LCA) of construction works. However, in terms of providing an accessible framework, as opposed to one seeking to address the requirements of a wide range of EN standards, for an industry with a culture of focusing on time and cost deliverables, the breadth of coverage of Gervasio and Dimova's proposed model could lead to difficulty in securing the desired (voluntary) buy-in. In addition to such industry perspectives, there is a value to considering perspectives such as the disruptive one adopted by Stahel (2019) when seeking to provide what the author argued as a common-sense attempt to explain the circular economy without adopting the standard 'black box' stance. In essence, Stahel argues for a behavioural toolbox approach to the workings of the circular economy. Whilst the free-wheeling nature of Stahel's discourse provokes and stimulates, the work presented in this paper does not, at this point, seek such a grand sweep.

The framework proposed in this paper enables the comparing (assessment) of options, thereby potentially contributing to increased "circularity" adoption and maturity in construction through enabling explicit and practical application of CE principles beyond the use of checklists, high-level principles, etc. The comparative nature of the framework, in conjunction with its intended use during the project initiation phase, provides a quantifiable basis for decision-making with respect to the level of circularity achievable by different design options. Over time, there is the potential for the industry to restructure its current supply-push nature (driven by materials and components developments) to a demand-pull nature as a quantifiable basis for circularity decision-making begins to pull the supply chain toward client/designer-led innovation.

1.3 CE and constructability in building projects

The authors are aware that the comparative nature of their proposed framework could be viewed as being philosophically similar with concepts of buildability/constructability. Indeed, early definitions of constructability share objectives with the CE concept; better knowledge and expertise management to review construction processes early in pre-construction and design stages to facilitate ease of construction (CIRIA, 1983), achieve overall project objectives (CII, 1986), and predict obstacles prior to the construction stage (IPENZ, 2008). Nima et al. (2001) listed 23 constructability concepts (CCs), many of which align with CE principles: use of prefabrication and off-site construction to avoid adverse weather conditions; planning for good site management, efficient use of resources and improved productivities; efficient use, reuse and recovery of temporary facilities and construction equipment; and improved collaboration through effective use of information technology. However, as discussed previously, the concept of CE has become a body of diverse discourse, the boundaries of which being such that CE, while having some philosophical similarities to constructability, does not have the same limitations of:

1. Incomplete addressing of the totality of the building lifecycle, typically with a focus on the construction stage, but not on the operation and decommissioning stages.
2. Motivated mostly by economic (efficiency and cost reduction), with little or no explicit consideration of environmental and social objectives.

While some constructability definitions have evolved (e.g. Gambatese et al., 2007) to acknowledge the whole building lifecycle, arguably culminating in the Institute for Research in Constructability (IRC, 2013) proposing a framework to show how the scope of 'constructability' grew from facilitating building construction to the whole construction lifecycle and improving a building's performance, differences between the two concepts remain. Nonetheless, it can thus be posited that both constructability and CE have shared objectives of retaining the *value* of resources for as long as possible, whilst also minimizing waste. They do, however, have differing approaches and a dearth of mutual recognition. Thus, while the proposed framework is not considered by the authors to be an explicit constructability tool, it is acknowledged that the constructability literature has a value in the context of the framework's conceptual development (Section 2.1).

1.4 Research aim and objectives

A 2017 paper (Adams et al, 2017) found that the level of awareness of CE in UK construction was lowest amongst clients, designers, and subcontractors. In terms of project decision-making, the awareness of CE amongst clients and designers is of most concern, and it should be acknowledged that any 'new' approach, method or technology is rarely fully adopted immediately, with adoption at the organizational level being considered particularly complex (Wisdom et al, 2014). Aarons et al. (2011) suggest that individual decision-makers in organizations may have difficulty selecting (on the basis of understanding and weighting of options) appropriate innovation(s) for specific problems, or their decision may be complicated by organizational, rather than individual, factors such as culture and values. However, factors such as leadership, innovation fit with organization norms and values, and organization attitudes/motivation toward innovations are suggested as key considerations (Wisdom et al, 2014). The authors therefore posit that, when communicating to clients, etc. about CE innovation, an ‘alignment’ of specific innovations with established norms within the UK construction industry, such as buildability/constructability, will improve the level of adoption.

To present CE innovations to the industry in the context of objectives shared with a known 'philosophy' (constructability) two actions are required:

Proposing a holistic framework, using a 'project lifecycle assessment (PLA)' approach, for circularity assessment of construction activities and practices.

Assessing conformity of constructability research and practices with CE requirements using the proposed framework.

The research aim is therefore to produce a means by which the UK construction industry can be supported in more readily transitioning to a full circular economy through the assessment of construction projects, firms, and practices against relevant circularity indicators (CIs). To achieve this aim, three objectives are identified:

1. Identify the requirements for a functioning construction circular economy.

2. Express those requirements in the context of relevant assessment indicators.
3. Structure the indicators within a standard project lifecycle through grouping into "circularity" themes (CTs) as the basis of an assessment framework.

The Project Lifecycle Assessment Circularity Indicators and Themes (PLACIT) proposed here could have been developed without any consideration of constructability. However, the innovative nature of this initial framework requires exploration of its applicability within a 'known' context such as constructability. This gives the proposed framework some meaning and provides an example of how construction processes would benefit from its adoption.

2. Research methods

To achieve the stated aim and objectives of this research, two main research methods were used. First, a conceptual framework was developed including circularity themes (CTs) and circularity indicators (CIs) representing high-level requirements of construction CE, and second, a systematic review of 'constructability' literature was conducted to assess its conformity with CE requirements using the proposed framework. This is discussed in more detail below.

2.1 Conceptual model development

A 'project lifecycle assessment (PLA)' stance is adopted as the basis on which to propose a new framework for "circularity" assessment in construction. The proposed Project Life-cycle Assessment Circularity Indicators and Themes (PLACIT) framework includes five main "circularity" themes relevant to the main stages in a construction project lifecycle, identified through reviewing the core CE literature in general, with the construction industry as a primary focus. Identified generic CE concepts and requirements were classified according to their relevance to these themes. Subsequently, these were grouped into twelve "circularity" indicators (CIs) embodying high-level requirements of CE relevant to different themes. The proposed framework facilitates “circularity” assessment of construction projects, firms and practices by measuring their engagement with different CIs (Figure 3 and Section 3.2). Thus, the model differs from existing models that track industry’s casual links with individual CE concepts. PLACIT can be used as a benchmarking tool, thereby helping industry practitioners identify areas of good practice, areas in need of circularity improvement, and, over time, support the restructuring of supply chains to adopt a production profile that functions on a demand-pull basis as clients and designers are able to evidence where their materials and components ‘needs’ lie.

2.2 Systematic review of the literature

The systematic review’s purpose was to identify literature evidencing an association between the ‘circular economy’ and different 'constructability' practices. Figure 1 demonstrates scope, search strategy, numbers of articles, and analytical strategy used in the systematic review. ‘Google Scholar’, ‘Scopus’, and ‘Web of Science’ databases were used to search, during December 2019, relevant literature with no time boundary, and using the following keywords: "Circular Economy" AND ("Building*" OR "Construction") AND (“Constructability" OR "Constructability" OR “Buildability"). This covers the three different ‘constructability’ terms used in the literature.

The initial search yielded an unexpectedly low number of hits (132) from the use of three search engines, along with a weak association between ‘circular economy’ and ‘constructability’, despite the well-established literature on both topics individually. For example, the initial search on 'Google Scholar' yielded 49,400 hits for “circular economy”, 42,200 hits for different terms of 'constructability', and only 117 hits for the association between the two topics, Figure 2. Similarly, ‘Scopus’ returned only 15 hits, while the 'Web of Science' returned no hits. Furthermore, 61.21% (71/116) of articles in the initial sample were published in the period 2018-2019 (Figure 2), revealing an accelerating trend of integrating CE and constructability concepts; an evolution that supports the previous suggestion (Section 1.3) of a means to widen CE adoption. The initial sample was refined by removing 16 duplicates and 50 non-articles, with the remaining 66 articles being reviewed for their relevance to the scope of this research, resulting in 9 articles being excluded as they provided no precise association between CE and constructability.

The final sample comprised 57 articles (empirical, conceptual, and conference papers) which were assessed for their relevance to different circularity themes and indicators included in the proposed circularity assessment framework. This helped investigate whether 'constructability' research and practices fulfil CE requirements and support the transition of construction to CE, and also identify areas for further circularity improvement.

3. Theory: a framework for “circularity” assessment

Any new direction in a market/economy ‘exposes’ the motivators of businesses and industry regulators which then result in different perspectives on the most effective way forward within what can be regarded as an ‘immature’ environment; as per the dynamics of the infant industry theory (Lee, 1997). Innovator businesses, for example, may seek to find a commercial opportunity in niches presenting difficult-to-address challenges, such as closing material loops within CE models. The offering by TerraCycle of recycling solutions for hard-to-recycle cigarette filters provides an example of an opportunity niche (TerraCycle, 2020), but as that niche environment matures an industry will coalesce around a decreasing number of perspectives, fragmentation of response becomes less, effectiveness improves and, over time, an industry ecology is developed that links closely to a key basic principle of CE; bio-memetics or the creation of cycles (loops) of materials and energy (de Abreu Ferreira et al, 2019).

The construction literature reveals a level of maturity with respect to both identifying and measuring waste materials, as one example of a potential bio-mimetic ‘loop’ within the industry, with such loops being constituted of triadic levels (comprising form, process, and ecosystem) of increasing requirements through which an industry must progress if full biomimicry is to be achieved (Banyus, 1997). Arguably, the UK construction industry, even in the context of waste management, is yet to evolve beyond Biomimetic Level 1: Imitation of organism features. El-Zeiny (2012) suggested three levels, with Level 3 comprising imitation of organism environment relationship). Thus, ‘full’ CE (Level 3) requires planning beyond waste management at the point of closing the construction process. The industry must therefore evolve/restructure to facilitate inclusion of other enabling and transversal factors promoting circularity throughout the *entire* project lifecycle.

3.1 A 'project lifecycle assessment (PLA)' approach: "circularity" themes

The authors argue for any circularity assessment framework to be developed so as to address the *totality* of the project lifecycle. This requires a link between CE requirements, as perceived in the literature, and different stages of the project lifecycle, some of which currently are not well-addressed, while others are absent. For example, the RIBA Plan of Work (2020) is a widely accepted model for a project lifecycle in the UK, and yet the 'decommissioning' or 'demolition' stage is not represented in this model and is considered outside the scope of project delivery. Such a model does not promote the creation of loops as a key principle for CE planning, thereby missing opportunities to progress through the three levels of bio-mimetics as indicators of the full transition of the UK construction industry to a CE. However, effectively supporting the industry's restructuring/evolution requires a more granular set of indicators appropriate to meaningful communication regarding circularity; addressing the industry in the 'language' of, for example, Biomimetics Level 2 (imitation of organism-community relationship: survival techniques, group management, communication, sensing and interaction (El-Zeiny, 2012)) is unlikely to encourage circularity adoption.

The proposed PLACIT framework seeks to achieve a more industry-friendly (than Levels 1 – 3 of the Biomimetics model) mode of communication by adopting a project lifecycle assessment (PLA) approach when assessing conformity of the constructability literature to those high-level requirements of CE referred to as circularity indicators (CIs) This also has the benefit of moving the industry away from its current approach of tracking its casual links with individual CE concepts (rather than adopting a more holistic perspective).

Figure 3 shows that the CIs identified, in the literature review (Section 3.2), are incorporated into the PLACIT framework, via being grouped into five themes relevant to the main stages in a construction project total lifecycle, Table 1. Themes include: (1) 'Design for Circularity' to link to the 'design stage', (2) 'Reduced Construction Impact' to link to the 'construction stage', (3) 'Sustainable Utilization & Maintenance' to link to the 'operation stage', (4) 'C&D Waste Mgmt.' to link to 'closing material loops' during 'construction' and 'decommissioning' stages, and (5) 'CE Mgmt.' for managerial requirements that cannot be included in other themes.

3.2 Circularity indicators (CIs) and CE assessment

CE concepts identified in the literature were initially classified according to their ‘headline’ relevance to a framework theme before then being grouped into sub-themes (considered as circularity indicators). On completion of this, a total of twelve circularity indicators (CIs) embodying relevant CE requirements were available to the proposed framework, Table 1. Designing for CE plays a transversal role in promoting circularity across the product lifecycle (Suárez-Eiroa et al., 2019), which signifies a fundamental change in design practices (De los Rios & Charnley, 2017). In Theme 1, (design for circularity), three CIs are available to assess "circularity" of design practices:

- CI-1: Design solutions to maximize future circularity,
- CI-2: Use of low-impact & innovative materials, and
- CI-3: Embed recycled materials in design.

CI-1 is future-focused, as it assesses plans for future circularity, such as at the project end-of-life, whereas CI-2 and CI-3 are present-focused, as they measure the level of circularity achieved during project delivery. Theme 2, (reduced construction impact) includes two CIs:

- CI-4: Reduced material inputs (more efficient construction processes and equipment sharing), and
- CI-5: Innovative construction methods (off-site construction and 3D printing).

Theme 3 (sustainable utilization and maintenance) provides a new understanding of the link between CE and sustainable development, through use of two CIs to group sustainability requirements relevant to the operation stage in construction projects:

- CI-6: 'Durability of building, asset, or project (efficient use, repair, maintenance, and project re-purposing,),
- CI-7: Reduced environmental impact of operation (carbon emissions, energy consumption, and waste production and management).

Theme 4 (C&D waste mgmt.), is concerned with closing material loops within construction, with CE frequently being viewed in the literature from the waste management perspectives (Kirchherr et al., 2017), and therefore two CIs address the key sources of waste in the construction process:

- CI-8: Construction waste mgmt.   (waste minimization strategies, and material and equipment recovery for onward reuse),
- CI-9: Demolition waste mgmt.   (integration of the 3R framework and waste management hierarchy).

Theme 5, (CE mgmt.), is added to include all CE managerial requirements that cannot be included in other groups. A transition to CE requires a systemic change in the conducting of business (McAloone & Pigosso, 2018), and a complete reform of both production and consumption processes (Yuan et al., 2006), which should be transformative (restructuring of industry production/consumption profiles) rather than only delivering incremental efficiency gains (Preston, 2012). Theme 5 therefore includes three CIs encapsulating managerial requirements relevant to:

- CI-10: New business models and strategies,
- CI-11: Planning, collaboration, and CE data mgmt., and
- CI-12: Education, training, and stakeholder CE awareness.

4. Results and discussion: circularity within constructability research

4.1 Engagement with circularity themes

In order to be more assured that the proposed framework addressed an actual gap in current provision regarding CE support within the construction industry, a final sample of 57 articles was analysed for evidence of deeper insights into the adoption of CE concepts in the constructability literature. Analysis included: standard bibliometric analysis, as well as quantitative and qualitative analysis with respect to the proposed PLACIT framework. Articles were quantitatively categorized according to their relevance to the proposed circularity Themes 1-5 and CIs 1-12 ". Moreover, studies in the final sample were qualitatively analysed to enrich discussions and capture the main argument within each. Results for different themes and associated CIs were depicted using radar diagrams to visually explore the engagement of constructability literature with individual CE concepts and thereby identify areas in need of further circularity development.

Data analysis evidences Theme 5 (CE Mgmt.) and Theme 1 (Design for Circularity) as receiving the highest levels of attention in the literature; 36.84% (21/57) and 35.09% (20/57) of the articles in the final sample engaged with these two themes respectively. This confirms the claimed transversal and enabling role of design frequently reported in the literature as facilitating circularity throughout the whole project lifecycle, and the need for better management and radical redesign/restructuring of well-established industry structures and supply chains, with the involvement of all stakeholders to facilitate a full CE transition for the industry. The three remaining themes evidence much lower levels of engagement in the final sample, with Theme 4 (C&D Waste Mgmt.) at 17.54% (10/57), and Theme 2 (Reduced Construction Impact) at 15.79% (9/57) Theme 3 (Sustainable Utilization & Maintenance) evidenced the lowest level of engagement, at 12.28% (7/57), Figure 4.

Three points are worthy of note regarding the variable levels of engagement in the final sample. Firstly, emphasis on two circularity themes is argued to support the earlier assertion regarding immaturity in the construction industry CE environment (Section 2.1). An emphasis on a small number of themes is indicative of an industry striving to move from the ‘known’ (its comfort zone – design and management themes) to the ‘unknown’ (its discomfort zone – reducing impact, achieving sustainable maintenance, and reducing waste beyond its current largely avoiding-the-landfill-tax response). Secondly, the situation where only one theme (Theme 3) with an explicit focus on sustainability interventions in CE topics, achieves the lowest level of engagement (12.28%) could be indicative of an industry environment in which there is an undue separation between, and a lack of clarity about their relationship, CE and sustainability concepts. The framework proposed in this paper has the potential for regulating this relationship to achieve a more holistic relationship. Thirdly, the overall picture (across the themes) suggests that engagement with circularity is focusing on aspirational qualitative concepts that are more related to circularity gains at some future point, rather than addressing the more challenging CIs that are more in tune with achieving actual (present to near future) circularity in construction practices. Evaluation of this possibility requires further consideration of the engagement with circularity indicators (CIs), which is discussed in the following section.

4.2 Engagement with circularity indicators (CIs)

The partial transition of construction to CE discussed above is more apparent when analysing the final sample against circularity indicators (CIs) in the proposed PLACIT framework, in that the analysis provides deeper understanding of those areas to be considered as being good practice and those appropriate for circularity improvements, Figure 4. The overall impression is that the constructability literature engages with those CIs that fall inside researchers' comfort zone(s), i.e. those related to design and construction stages, requiring little additional effort while yielding acceptable results. This form of engagement has similarities with the innovation diffusion theory and related S-curve of Roger (Wonglimpiyarat, 2005) and indicates an industry at the first stage of CE adoption (innovators).

The high level of engagement with Theme 1 highlights the role that design plays in promoting circularity throughout the whole building lifecycle. However, analysis revealed that this engagement is mostly aspirational, in that more articles are concerned with 'design solutions to maximize future circularity' (28.07%) than are with the 'use of low impact &

innovative materials' (7.02%), while the 'embed recycled materials in design' indicator was totally overlooked (0%). This highlights the urgent need to update design tools, e.g.: BIM libraries, so as to facilitate the embedment of the newly available circular and innovative low impact materials and commence the restructuring/re-profiling of associated supply chain information in design practices. This represents a gap in the current literature, thereby providing directions for future research as well as an opportunity for further enhancing circularity in construction.

The proposed framework includes three construction-related CIs for which inconsistent levels of engagement were identified: CI-8 construction waste mgmt. (construction waste minimization and materials and equipment recovery for onward reuse) at 12.28% (7/57); CI-5 innovative construction methods (off-site construction and 3D printing) at 10.53% (6/57), and CI- 4 reduced material inputs' (using efficient construction processes and equipment sharing) at 3.51% (2/57). Moreover, articles showed little interest in CI-9 (demolition waste mgmt.) at 7.02% (4/57), further evidencing a weak link with CE concepts related to buildings' end-of-life stage in the constructability literature. Articles containing material relevant to CI-9 focused on integrating the 3R framework (reduce, reuse and recycle) and waste management hierarchy within the management of demolition waste. The authors posit that the low level of engagement with this CI may reflect the current industry culture of potentially considering waste management to be a requirement to meet a legally imposed minimum level of performance at the end of a building's lifespan, rather than an opportunity to 'design in' improved circularity during the project's design stage.

Such a position is perhaps supported by the unexpected finding that articles revealed little engagement with Theme 3 indicators relevant to the 'operation' stage: CI- 6 ('durability of building' relevant to efficient use/repair/maintenance and building repurposing) at 8.77% (5/57), and CI-7 (reduced environmental impact of operation) at 1.75% (1/57). The low engagement with CI-6 could be argued to fit, in the UK industry context, with a tradition/mind-set in which durability considerations are solely a matter for the client in relation to the project budget. The low level of engagement with CI-7 is more difficult to rationalize but, again, may be a result of matters relevant to it simply being considered a case of meeting a minimum legal requirement and therefore not ‘on the radar’ as far as circularity or constructability is concerned. These interpretations would be of interest as a possible area of further research.

Overall, these relative low levels of engagement add to the suggestion that the industry currently focuses primarily on aspirational qualitative themes and has yet to address the more challenging quantitative circularity indicators. However, the analysis also revealed the possibility of a nascent relationship with the CIs of Theme 5 (CE mgmt.), with each of the three at 12.28% (7/57). This level of engagement across all three of the CIs is perhaps evidence of the literature (researchers) seeking opportunities offered by new CE managerial strategies relevant to these indicators. Nonetheless, this apparent imbalance across the 12 CIs, combined with the low engagement with sustainability-related indicators, are argued to be reflective of the separation between CE, as an emerging paradigm, and sustainability concepts; despite the traditional view of circularity being subordinate to sustainability.

5. Conclusions

This paper proposes a new framework for “circularity assessment in construction projects and uses this framework to assess conformity of 'constructability' research and practices with CE requirements. Five incremental contributions to addressing key limitations on the industry’s circularity transition are identified. However, prior to presenting these it is relevant to briefly consider the role of data in the effectiveness of any circularity model or framework. This is a recurrent consideration in Gervasio and Dimova’s (2018) LCA model, and one they addressed by using the data requirements (structure) stated within ISO14044:

- Time-related coverage - datasets should be recent or updated within the last 10 years for generic data and 5 years for specific data from producers;
- Geographical coverage – according to the aim of the study, the geographical area from which data is collected should be representative;
- Technological coverage – all relevant technologies should be covered, and they should reflect the reality for each product;
- Completeness – datasets should be complete according to the goal and scope of the analysis.

The authors have, in this paper, sought to provide a structured approach to the use of data (and their proposed framework includes a Circularity Indicator specific to data management) to enhance the proposed framework’s effectiveness as a valid approach to supporting the industry’s transition to a fully circular economy.

The ‘Project Lifecycle Assessment Circularity Indicators and Themes (PLACIT)’ framework has the potential to make a significant contribution toward addressing, over time, two key limitations on the construction industry's transition to a full circular economy (CE). These include: the lack of a holistic framework for "circularity" assessment, and the ambiguity (blurring of conceptual boundaries; section 1.1) between CE and 'sustainability' concepts. The overall contribution, i.e. transition to CE, is suggested as being achieved by incremental, smaller contributions over differing timescales.

First, the holistic approach to "circularity" assessment adopted in PLACIT is innovative from different perspectives. It shifts attention from focusing on a specific stage in a project lifecycle (as seems to be the case currently with constructability) or individual CE concepts, to considering high level requirements of CE for different stages in a project lifecycle. Such a change can be expected to have a significant environmental impact in construction, enhanced by the framework providing clients, designers and other construction practitioners with a sophisticated benchmarking tool to identify areas of good practice and those appropriate for focused "circularity" improvements. Moreover, PLACIT is the first framework to focus on rating (and thus enabling comparing) "circularity", rather than sustainability, within project decisions. 'Sustainability' notions relevant to the 'operation' stage are integrated into one indicator (CI7: Reduced Environmental Impact of Operation) in a broader and more circularity-oriented, rather than sustainability-oriented, framework. This represents a shift in previous understanding of the link between CE and 'sustainability' in construction, thereby 'flipping' the current perspective of CE being subordinate to sustainability.

Second, PLACIT portrays the complex nature of the transition to CE in construction, where totality of the framework, including circularity themes (CTs) and circularity indicators (CIs), needs to be considered to achieve full transition. Results indicate a currently supply-push business environment and raise concerns about maturity of the construction industry, in terms of the complex transition to CE. For example, high engagement with some indicators within the industry's comfort zone; namely CI1 (Design solutions to Maximize Future Circularity - 28.07%), CI8 (Const. Waste Mgmt. - 12.28%) and different CE management indicators (CI10, CI11 and CI12 – 12.28%), is only aspirational and has not resulted in actual circularity (see low results for CI3, CI9 and CI4 above). Low results for individual CIs may seem casual, simple, and unrelated; however, a cross-theme approach can establish that more complex CE solutions may be required. For example, effective C&D waste management and closing material loops require close collaboration between all stakeholders, active CE data management, new business models in construction supply chains, and effective use of technologies such as BIM tools to combine circular materials in design practices. This requires restructuring/re-profiling of construction supply networks and internal relationships, and active involvement of all project stakeholders.

Third, the circularity indicators (CIs) comprising the framework, being grouped in circularity themes (CTs) relevant to project lifecycle stages, facilitate the transition to a more demand-pull environment as they support the industry in identifying areas for further "circularity" improvements and develop an integrated progressive addition of those CIs not currently addressed sufficiently. The unenviable position reported in the previous point reveals an industry predisposed to achieve "easy CE hits" by engaging with certain CIs that fall inside its comfort zone, while scoring very low on other more challenging CIs. For example, low engagement with CI3 (Embed Recycled Materials in Design – 0%) reveals issues with the actual closing of material loops in construction, and CI4 (Reduce Material Inputs – 3.51%) indicates inability to decouple economic growth from resource consumption. Further support is required to achieve the right balance between all CIs, including the addressing of supply-push and demand-pull factors, through higher engagement with CI12 (Education, Training, and Stakeholders CE Awareness), which scored low (12.28%), and better CE governance. This support is considered as relevant to medium-term development of CE within the construction industry, particularly regarding achieving the initial development of an informed, client/designer-led, demand-pull culture focused on materials and components circularity.

Fourth, CI-6 (Durability of Building – 8.77%) evidenced engagement with topics including building repair, maintenance and repurposing, which defines a potentially new waste type (maintenance waste) within this relationship that has not been well addressed in current C&D waste management literature. This potentially places a more explicit focus on issues of material/component durability, and potentials for improved "circularity" of materials during the project 'operation' stage.

Fifth, the framework has the potential to aid in regulating the boundaries of a currently ill-defined relationship in the literature between 'sustainability' and CE concepts. Low engagement with CI-7 (Reduced Environmental Impact of Operation – 1.75%) suggests that concepts associated with this indicator are more relevant to 'sustainability' than CE, and may not need to be considered in a "circularity" rating framework i.e. PLACIT. In addition, there is a possibility that such apparent anomalies result from the previously discussed industry assumption of associated concepts (carbon emissions, energy consumption, etc.) being covered by legislation. Such apparent anomalies will be investigated further in the next stage of the research (funded by the Association for Project Management (APM) - see Acknowledgement section), using expert feedback. This would help decide whether low engagement with some CIs highlights these as areas for further circularity improvement or as concepts more related to 'sustainability' assessments that do not need to be included in PLACIT.

As any other research, this study has its own limitations. The conceptual framework proposed in this paper, i.e. PLACIT, has not been validated using empirical feedback from industry practitioners. Moreover, this paper offers no evidence of its potentials to support decision-making in real-life project scenarios and does not address barriers to the full transition to CE in related to CTs and CIs included in PLACIT. Finally, although the scope of this study is limited to the building sector, use of PLACIT and findings reported in this paper may extend to other construction sectors and project-based industries; which requires further investigation. The first two authors listed on this paper have commenced a funded research project (see Acknowledgement) which seeks to verify and validate the proposed framework (PLACIT) using real-life project example(s) and feedback from construction practitioners to ensure its adequacy for "circularity" assessment and explore its potentials for supporting decision-making in construction projects. This will allow the connection between PLACIT and constructability to drop away.

Acknowledgement

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Table 1. The proposed 'Project Lifecycle Assessment Circularity Indicators and Themes (PLACIT)' framework (Abadi and Sammuneh, 2020)

Circularity Themes	Circularity Indicators
Design for Circularity in Construction (Design Stage)	• **CI-1: Design Solutions to Maximise Future Circularity:** (design for disassembly, longevity, and modularisation • **CI-2: Use of Low-impact Innovative Materials** • **CI-3: Embed Recycled Materials in Design**
Reduced Construction Impact (Construction Stage)	• **CI-4: Reduced Material Inputs:** efficient const. processes, sharing equipment • **CI-5: Innovative Construction Methods:** e.g. off-site construction, 3D printing
Sustainable Utilisation & Maintenance (Operation Stage)	• **CI-6: Durability of Building, Asset, or Project:** efficient use, repair, maintenance, and repurpose • **CI-7: Reduced Environmental Impact of Operation:** CO2 emissions, energy consumption, and domestic waste Mgmt.
C&D Waste Mgmt. (Closing Material Loops)	• **CI-8: Construction Waste Mgmt.:** waste minimisation material & equipment recovery for onward reuse • **CI-9: Demolition Waste Mgmt.:** Integrating the 3R framework & waste mgmt. hierarchy
CE Mgmt. (Business Models, Education, and Data Mgmt.)	• **CI-10: New Business Models and Strategies** • **CI-11: Planning, Collaboration, and CE Data Mgmt.** • **CI-12: Education, Training, and Stakeholders CE Awareness**

Figure 1. Scope, keywords and strategy adopted in the systematic review

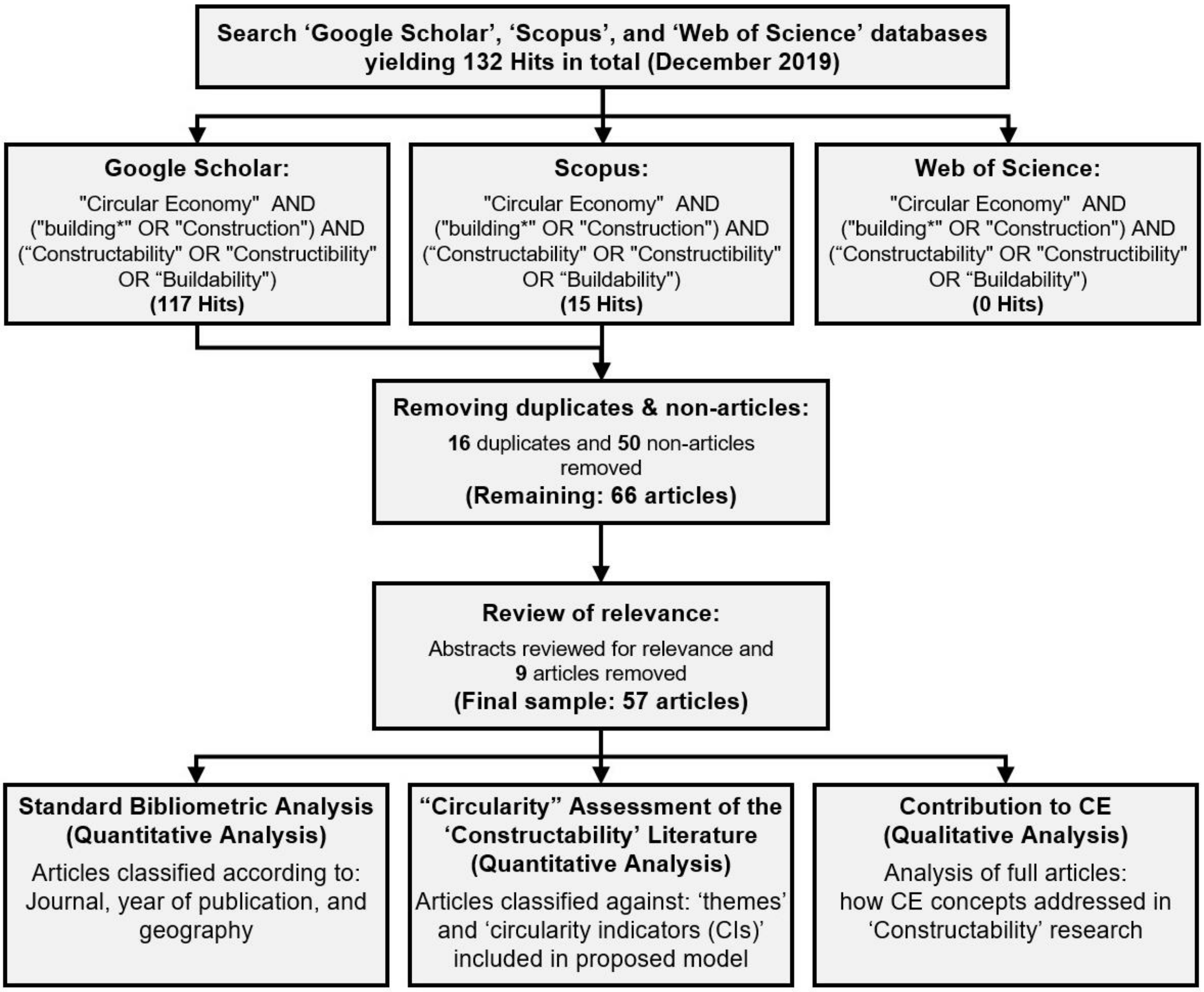
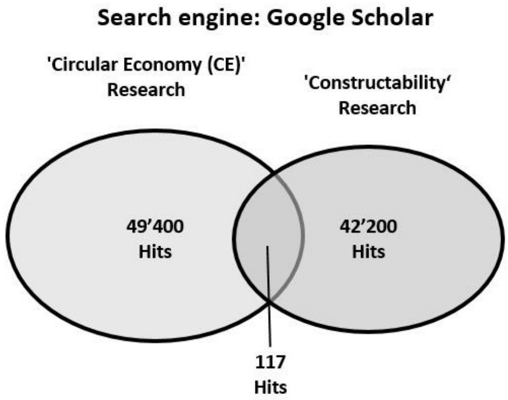


Figure 2. The association between CE and 'Constructability' in literature & the chronological distribution of articles in the systematic review



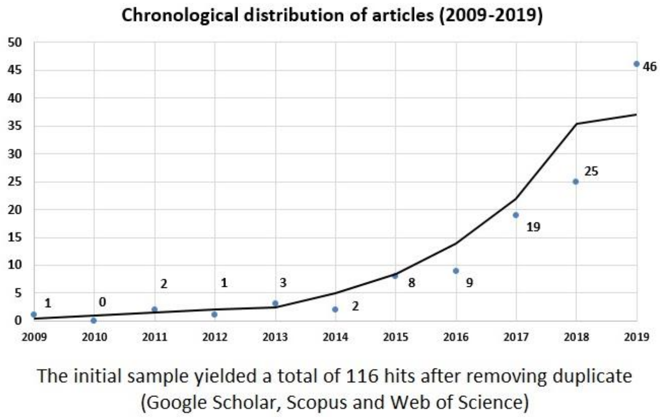


Figure 3. “Circularity” Themes and Indicators (CTs & CIs) in the proposed PLACIT Framework

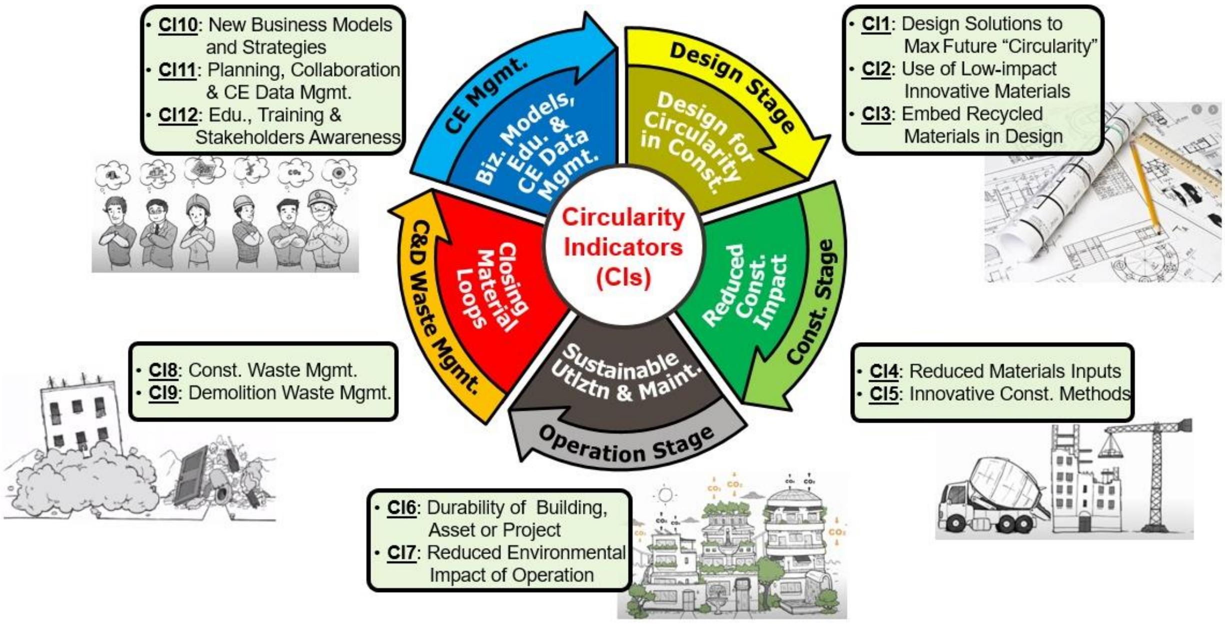


Figure 4. Engagement of the literature with "Circularity" Themes& Indicators (CTs & CIs)